

FILM COEFFICIENTS FOR MASS TRANSFER DURING LIQUID ATOMIZATION

BY

MILFORD CHARLES TASSLER

B.S., Carnegie Institute of Technology, 1947
M.S., University of Illinois, 1949

AN ABSTRACT OF A THESIS

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
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INTRODUCTION

The object of this work was to determine film coefficients for mass transfer in the venturi atomizer by measuring the rate of desorption of carbon dioxide from aqueous solutions. The atomizing venturi consists of a conventional venturi into which liquid is introduced at the throat. The high relative velocity of the gas stream past the liquid causes its disruption into a spray of many small droplets, thus providing a large surface for mass transfer from one phase to the other. Johnstone and Roberts (1) measured the overall efficiency of a venturi with rectangular throat as a gas absorber. Feild (2) and Tassler (3) measured the gas film absorption coefficients for the absorption of sulfur dioxide by an alkaline solution in a small venturi atomizer with a throat of circular cross-section. Ekman and Johnstone (4) used a similar device to study the performance of the atomizer for collecting oil aerosols. Feild (5) measured the collection of aerosol particles by atomized sprays.

In this work, the rate of transfer close to the point of liquid injection was measured using a system in which the liquid film resistance controls the rate of transfer. The high rates of transfer and the brief time of contact between the gas and liquid suggest the possible use of the venturi atomizer as a reactor for carrying out mixed-phase reactions.

THEORY

The extent of the contact surface between gas and liquid during absorption or desorption is important in determining the transfer between phases. In addition, the degree of turbulence existing within the liquid is important, especially in a system in which the liquid film controls. The use of sprays ordinarily is not considered practical in such a system,

because relatively little mixing occurs within a slowly moving drop. Consequently, a concentration gradient is established within the drop, decreasing the effective driving force. When the principle resistance to transfer lies in the gas film, a moving drop is constantly exposed to fresh gas, minimizing the formation of a concentration gradient of solute gas in the film immediately surrounding the drop. In the venturi atomizer, excellent mixing within liquid particles is obtained because of the distortion caused by the action of the high velocity gas stream, and a very large surface is developed for the transfer. Although only desorption has been studied in the present work, it would be expected that the venturi atomizer serve equally well for the absorption of a slightly soluble gas.

For purposes of comparison, it is desirable to separate the terms in the experimentally determined overall transfer coefficient, $K_L a$. This has been done, by an empirical method using an equation (6) for estimating the volume-surface mean diameter of the droplets formed in the atomizer,

$$D_0 = 585\sqrt{\sigma} / v\sqrt{\rho} + 597(\mu / \sqrt{\sigma\rho})^{0.4} (1000 Q_L / Q_A)^{1.5}$$

where D_0 is in microns; v is the relative velocity between the gas and liquid streams, m./sec.; μ is the liquid viscosity, poises; ρ is the liquid density, gms./ml.; σ is the surface tension of the liquid, dynes per centimeter; and Q_L/Q_A is the volumetric flow ratio of liquid and air. The applicability of the equation has been established for the venturi atomizer (7), and estimated surface of the drops has been used for the correlation of absorption and aerosol removal data. There may be a question of its use in the zone in which atomization is not complete and for velocities below the range suggested for its application. Even though atomization may be incomplete, it is probable that the surface area of the films and filaments would be at least proportional to the area of the drops ultimately formed and forming. At any rate, it appears that the equation can be used for the estimation of the relative amounts of surface existing in the atomization zone, because

the ultimate area is related to the forces acting during atomization.

EXPERIMENTAL

The venturi used in this work was made of Lucite and was placed in a 3-inch pipe line. The convergent section had a total angle of 25° . The throat was 3 inches long and the inside diameter was $1\frac{1}{8}$ inches. The angle of the divergent section was 4° . Liquid was injected at the upstream edge of the throat through a combination of five stainless steel hypodermic tubes of diameter 0.030 inches. Gas velocity measurements were made using a metering venturi upstream from the atomizing venturi.

Aqueous solutions of carbon dioxide were made up using distilled water which had been further purified by passing through a mixed Amberlite exchange resin bed and were fed into the gas stream at fixed rates. Samples of the spray were collected at several points along the axis of the throat and analyzed by mixing with standard barium hydroxide solution to precipitate the undesorbed carbon dioxide as barium carbonate. The residual concentration of barium hydroxide was determined from the change in electrical conductivity of the solution. Varying initial concentrations of carbon dioxide were used to determine the effect of liquid concentration. Radial traverses indicated a constant concentration profile of the droplets collected under fixed operating conditions.

The overall transfer coefficients calculated from the data varied with gas velocity, liquid feed rate, and distance from the point of liquid injection. At constant gas velocity and liquid rate, $K_L a$ passes through a maximum at distances less than $1\frac{1}{2}$ inches. The value of the maximum is essentially constant at a given gas velocity, with decrease in the liquid rate causing a shift in the position of the maximum closer to the point of liquid injection. Decreasing gas velocity causes the values of the transfer coefficients to decrease. After passing through the maximum, $K_L a$ decreases abruptly with distance from the liquid source.

CONCLUSIONS

Because of the turbulence existing in the atomization zone, the venturi atomizer gives high rates of mass transfer between liquid and gas for a system in which the liquid film resistance controls. The overall transfer coefficients are dependent upon both gas velocity and liquid rate, with best results obtained with low liquid rates and high gas velocities. The initial liquid concentration has no effect on the fractional desorption. The use of five nozzles gives results identical with those obtained using a single nozzle, thus indicating that the atomization in the immediate vicinity of a nozzle is independent of the presence of other nozzles.

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VITA

Milford Charles Tassler was born on September 29, 1921, in Sebeka, Minnesota. After graduating from the Walnut Hills High School in Cincinnati, Ohio, in 1939, he entered the Carnegie Institute of Technology as a George Westinghouse Scholar. In 1942, he enlisted in the Army of the United States and served in the American and European Theaters. After discharge from the Army in 1946, he returned to the Carnegie Institute of Technology and received the Degree of Bachelor of Science in Chemical Engineering in May, 1947. He entered the Graduate College of the University of Illinois in 1947 and received the Degree of Master of Science in Chemical Engineering in February, 1949. He held a Graduate Assistantship in Chemical Engineering from September 1947 to June 1948 and subsequently held the Standard Oil Company (Indiana) Fellowship in the academic years 1948-1949 and 1949-1950. He is a member of Tau Beta Pi, Sigma Xi, Phi Kappa Phi, and Phi Lambda Upsilon.

